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Enhanced uplink non-orthogonal multiple access for 5G and beyond systems

Key words: Uplink non-orthogonal multiple access; Generalized Welch-bound equality; Multi-level received powers; Sequence grouping

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Motivations

1. Power as one of MA signatures has been employed for DL MUST in Release 13 and power domain NOMA is widely investigated in academia. However, NOMA in Releases 14 and 15 usually assumes equal received power and power has not so far been fully exploited.

2. Considering the near-far effect, power difference is a natural phenomenon in wireless networks. How to employ the feature of power difference to further enhance the performance of uplink NOMA is an important issue.

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Main idea

1. State-of-the-art of uplink NOMA:

(1) NOMA schemes for standardization in 3GPP, unified structure at transmitter and advanced receivers;

(2) Existing sequences-based NOMA schemes;

2. Proposed NOMA enhancements:

(1) Capacity optimal sequences under unequal received power-generalized welch-bound equality (GWBE) sequences;

(2) User grouping with multi-level received powers;

(3) Sequence grouping.

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(1) Capacity optimal sequences under unequal received power GWBE sequences

- Motivation: For better receiving performance

K: Number of users
P_i: Received power of user i
$\boldsymbol{s}_i$: Spreading sequence of user i
$\boldsymbol{n}$: AWGN with zero mean and variance σ^2

$$\boldsymbol{y} = \sum_{k=1}^{K} \sqrt{P_k}\boldsymbol{s}_k x_k + \boldsymbol{n},$$

  - Ergodic sum capacity under AWGN channel:

$$C_{sum} = \frac{1}{2N}\log_2\left(\det\left(\mathbf{I} + \frac{1}{\sigma^2}\boldsymbol{SPS}^H\right)\right)$$

  - SINR under MF receiver

$$SINR_k = \frac{P_k^2}{\sum_i P_k P_i |\boldsymbol{s}_k^H \boldsymbol{s}_i|^2 - P_k^2 + P_k\sigma^2}$$

- Cross-correlations of spreading sequences

$$R_s = \sum_{i,k} P_k P_i |\boldsymbol{s}_k^H \boldsymbol{s}_i|^2 = \left\|\boldsymbol{P}^{1/2}\boldsymbol{S}^H\boldsymbol{S}\boldsymbol{P}^{1/2}\right\|_F^2 = \|\boldsymbol{SPS}^H\|_F^2$$

  - WBE sequences:

$$\min_{\boldsymbol{S}} \sum_{i,k} |\boldsymbol{s}_k^H \boldsymbol{s}_i|^2 = \frac{K^2}{N}$$

    - Only optimal for equal received power: $\boldsymbol{P} = \mathbf{I}$ (not practical)

  - **GWBE sequences**:

$$\min_{\boldsymbol{S}} \sum_{i,k} P_k P_i |\boldsymbol{s}_k^H \boldsymbol{s}_i|^2 = \frac{1}{N}\left(\sum_k P_k\right)^2$$

    - **Optimal for arbitrary received power**

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(2) User grouping with multi-level received powers

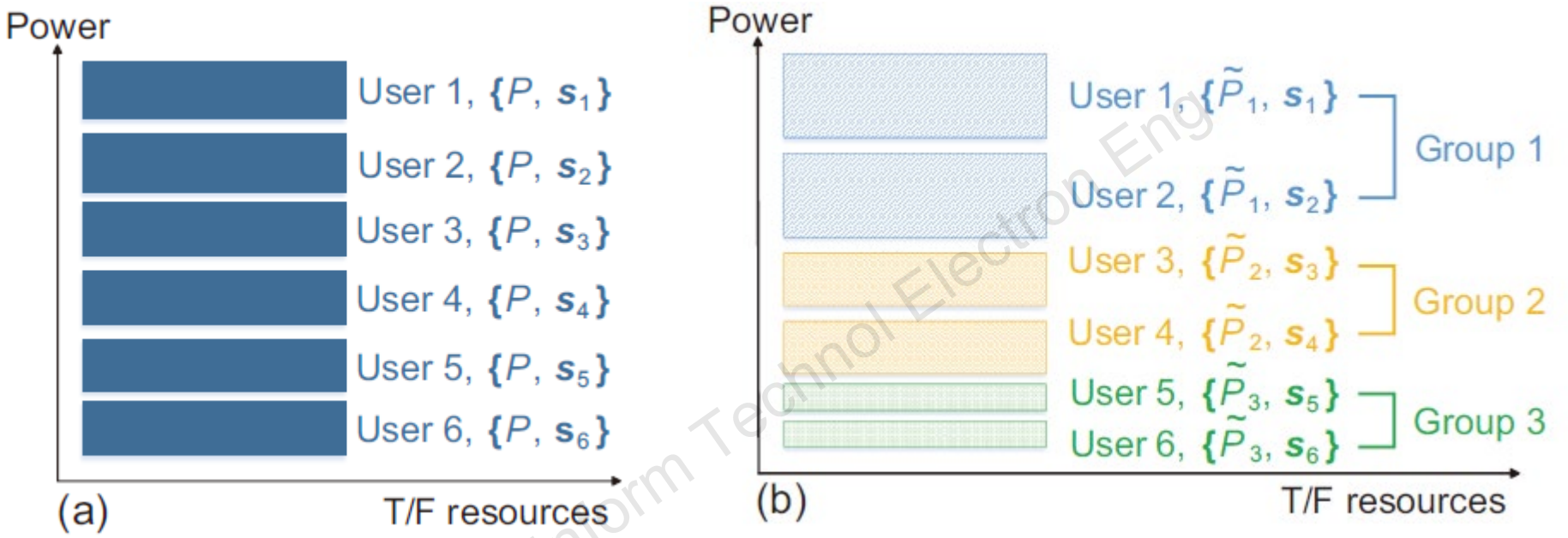


Fig. 2 Illustration of non-orthogonal multiple access (NOMA) with six users ($K = 6$): (a) NOMA with equal received power; (b) NOMA with user grouping and multi-level received powers ($G = 3$, $K_1 = K_2 = K_3 = 2$, and $\tilde{P}_1 > \tilde{P}_2 > \tilde{P}_3$)

To facilitate SIC receiving, users are divided into multiple groups:

(1) Users in one group have equal received power

(2) Received powers of users in multiple groups are different

(3) Sequence grouping

Observation:

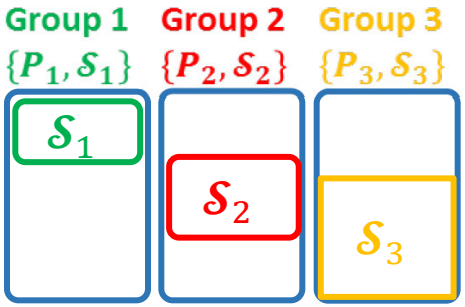
With successive interference cancellation, SINR of UE_k is determined by the cross-correlations between $\boldsymbol{s}_k$ and sequences of users with lower received power than UE_k

Sequences can be divided into groups to reduce intra- and inter-group interference:

1. Large power offset between adjacent groups:

(1) Intra-group interference dominate;

(2) Sequences grouping based on minimal total squared cross-correlations in each group.



2. Small power offset between adjacent groups

(1) Both intra- and inter- group interference dominate;

(2) Sequences grouping based on minimal total squared cross-correlations in groups with lower received powers.

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Major results

1. **Under fixed MA signature allocation:**
   (1) GWBE sequences can achieve lower BLER;
   (2) Multi-level received powers can enhance the performance;
   (3) Sequence grouping can achieve better performance.

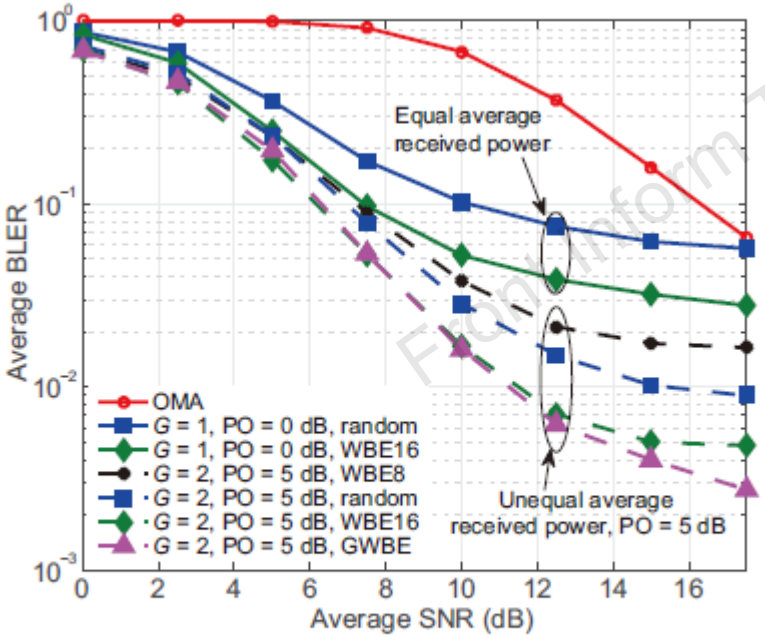


Fig. 4 Average block error rate (BLER) under different sequence pools and power offset (PO)

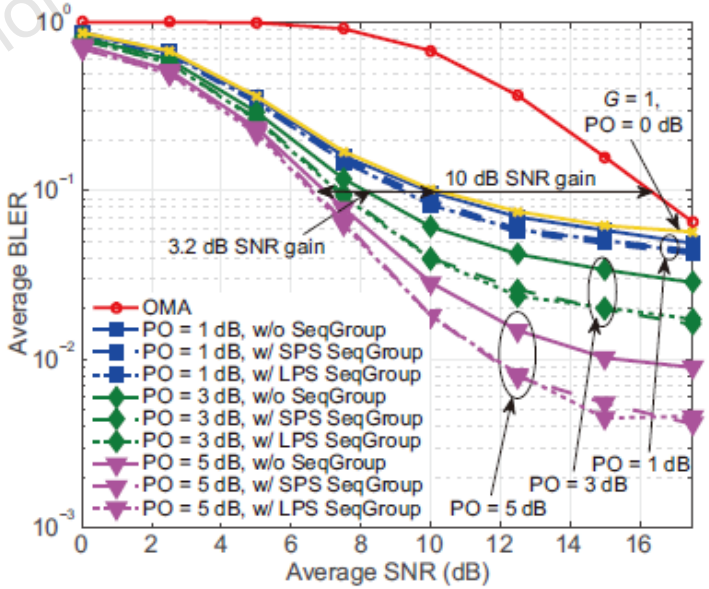


Fig. 8 Average block error rate (BLER) under different power offsets and sequence grouping methods. Random complex sequences are used. 'LPS' and 'SPS' denote large and small power offsets, respectively

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Link-level simulation results

1. **Under random MA signature selection:**

   Multi-level received powers (i.e., NOMA with user grouping) can increase the signature pool size → Better performance

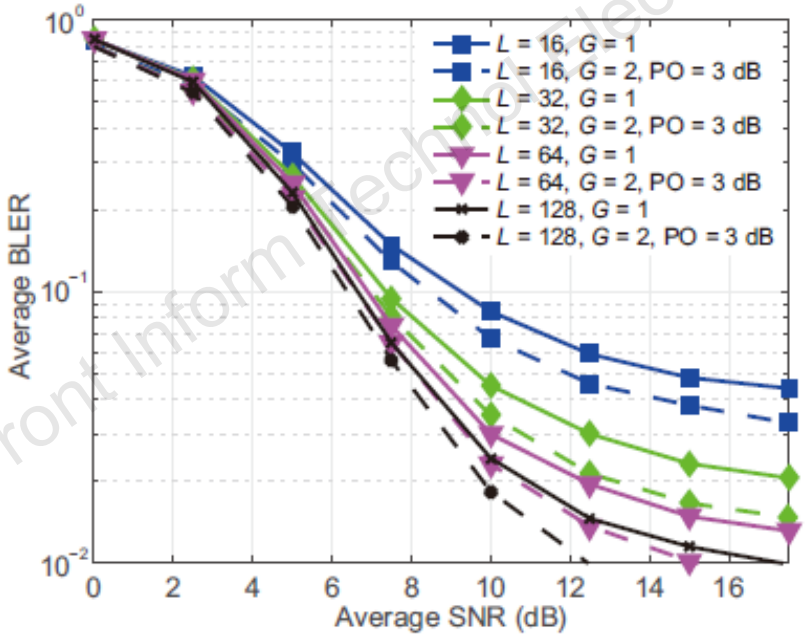


Fig. 11 Average block error rate (BLER) under different number of WBE sequences and groups. Random signature selection is used. TDL-C channel with 300 ns delay spread is considered

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Conclusions

1. We proposed to use power as part of the MA signature.
2. Three enhancements were proposed for uplink NOMA:
   (1) Optimal sequence design, i.e., GWBE sequences, for sequence-based NOMA schemes;
   (2) User grouping with multi-level received powers;
   (3) Sequences grouping based on cross-correlations.
3. Evaluation results showed that the proposed enhancements could achieve better performance under connectivity and reliability.

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